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Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	2	"wo 00/07184"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:31
L2	1	lambert-nicolass.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:33
L3	0	lambert-nicolass-$.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:42
L4	14	denissen-adrianus-johannes-maria.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:50
L5	25	denissen-adrianus-johannes-m$.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:52
L6	62	denissen-adrianus-j$.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 13:59
L7	24	lenssen-kars-michiel-hubert.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB	OR	ON	2006/09/04 14:10

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L8	52	lenssen-kars-michiel-h$.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:15
L9	54	lenssen-kars-m$.in.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:19
L10	65336	("PHILIPS CORPORATION" "PHILIPS ELECTROICS NORTH AMERICA CORPORATION" "PHILIPS ELECTRONIC" "PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED" "PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LTD. " "PHILIPS ELECTRONIC NORTH AMERICA CORPORATION" "PHILIPS ELECTRONIC NORTH AMERICA CORP." "PHILIPS ELECTRONICS AND ASSOCIATED INDUSTRIES LIMITED" "PHILIPS ELECTRONICS AND PHARMACEUTICAL INDUSTRIES" "PHILIPS ELECTRONICS NORTH AMERICA" "PHILIPS ELECTRONICS NORTH AMERICA CORPORATIOIN" "PHILIPS ELECTRONICS NORTH AMERICA CORPORATION" "PHILIPS ELECTRONICS NORTH AMERICA CORP." "PHILIPS ELECTRONICS NORTH AMERICA INC." "PHILIPS ELECTRONICS NORTH AMERICAN CORPORATION" "PHILIPS ELECTRONICS NORTH AMERICAN CORP." "PHILIPS ELECTRONICS N.V." "PHILIPS ELECTRONICS UK LIMITED" "PHILIPS INDUSTRIAL COMPONENTS- INC." "PHILIPS INDUSTRIES INC." "PHILIPS KOMMUNIKATIONS INDUSTRIE AG" "PHILIPS KOMMUNIKATIONS INDUSTRIE AKTIENGESELLSCHAFT" "PHILIPS S.P. A.").as.	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:20
L11	5463	(magnetic or magneto$1resistive or (magneto adj resistive)) with security	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:23
L12	19	l10 and l11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:31
L13	272	(365/185.04).CCLS.	US-PGPUB; USPAT	OR	OFF	2006/09/04 14:30

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L14	4	l13 and l11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:36
L15	545	(365/228).CCLS.	US-PGPUB; USPAT	OR	OFF	2006/09/04 14:36
L16	0	l15 and l11	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:36
L17	497	l15 and @ad<="20021218"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:37
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S2	172715	(magnetic or magneto$1resistive or (magneto adj resistive)) adj2 (element or memory or storage or device)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:23
S3	2892	first adj2 S2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:26

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S4	2864	second adj2 S2	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:27
S5	22067	magnetization near2 direction	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:28
S6	138093	external adj3 (field or flux or force)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:35
S7	11	S3 with S4 with S5 with S6	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:46
S8	15	S3 same S4 same S5 same S6	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:52
S9	554466	pre$1set or (pre adj set)	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 21:52
S10	52	S9 with S5	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/02 22:17
S11	63	magnetic adj2 security adj2 device	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 13:26

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S12	2	S11 and @ad<="20021218"	US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT ; IBM_TDB	OR	ON	2006/09/04 14:37

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Ferromagnetism

From Wikipedia, the free encyclopedia

Ferromagnetism is the "normal" form of magnetism which most people are familiar with, as exhibited in horseshoe magnets and refrigerator magnets, for instance. It is responsible for most of the magnetic behavior encountered in everyday life. All permanent magnets are either ferromagnetic or ferrimagnetic, as are the metals that are noticeably attracted to them.

Historically, the term "ferromagnet" was used for any material that could exhibit spontaneous magnetization: a net magnetic moment in the absence of an external magnetic field. This general definition is still in common use. More recently, however, different classes of spontaneous magnetization have been identified when there is more than one magnetic ion per primitive cell of the material, leading to a stricter definition of "ferromagnetism" that is often used to distinguish it from ferrimagnetism. In particular, a material is "ferromagnetic" in this narrower sense only if *all* of its magnetic ions add a positive contribution to the net magnetization. If some of the magnetic ions *subtract* from the net magnetization (if they are partially *anti*-aligned), then the material is "ferrimagnetic". If the ions anti-align completely so as to have zero net magnetization, despite the magnetic ordering, then it is an antiferromagnet. All of these alignment effects only occur at temperatures below a certain critical temperature, called the Curie temperature (for ferromagnets and ferrimagnets) or the Néel temperature (for antiferromagnets).

Contents

Ferromagnetic materials

There are a number of crystalline materials that exhibit ferromagnetism (or ferrimagnetism). The table at right lists a representative selection of them here, along with their Curie temperatures, the temperature above which they cease to exhibit spontaneous magnetization (see below).

Ferromagnetic metal alloys whose constituents are not themselves ferromagnetic in their pure forms are called Heusler alloys, named after Fritz Heusler.

One can also make amorphous (non-crystalline) ferromagnetic metallic alloys by very rapid quenching (cooling) of a liquid alloy. These have the advantage that their properties are nearly isotropic (not aligned along a crystal axis); this results in low coercivity, low hysteresis loss, high permeability, and high electrical resistivity. A typical such material is a transition metal-metalloid alloy, made from about 80% transition metal (usually Fe, Co, or Ni) and a metalloid component (B, C, Si, P, or Al) that lowers the melting point.

One example of such an amorphous alloy is $Fe_{80}B_{20}$ (Metglas 2605) which has a Curie temperature of 647 K and a room-temperature (300 K) saturation magnetization of 125.7 milliteslas (1257 gauss), compared with 1043 K and 170.7 mT (1707 gauss) for pure iron from above. The melting point, or more precisely the glass transition temperature, is only 714 K for the alloy versus a melting point of 1811 K for pure iron.

A selection of crystalline ferromagnetic (* = ferrimagnetic) materials, along with their Curie temperatures in kelvins (K). (Kittel, p. 449.)

Material	Curie temp. (K)
Co	1388
Fe	1043
$FeOFe_2O_3$*	858
$NiOFe_2O_3$*	858
$CuOFe_2O_3$*	728
$MgOFe_2O_3$*	713
MnBi	630
Ni	627

MnSb	587
$MnOFe_2O_3$*	573
$Y_3Fe_5O_{12}$*	560
CrO_2	386
MnAs	318
Gd	292
Dy	88
EuO	69

Physical origin

The property of ferromagnetism is due to the direct influence of two effects from quantum mechanics: spin and the Pauli exclusion principle.

The spin of an electron, combined with its orbital angular momentum, results in a magnetic dipole moment and creates a magnetic field. (The classical analogue of quantum-mechanical spin is a spinning ball of charge, but the quantum version has distinct differences, such as the fact that it has discrete up/down states that are not described by a vector; similarly for "orbital" motion, whose classical analogue is a current loop.) In many materials (specifically, those with a filled electron shell), however, the total dipole moment of all the electrons is zero (e.g., the spins are in up/down pairs). Only atoms with partially filled shells (e.g., unpaired spins) can experience a net magnetic moment in the absence of an external field. A ferromagnetic material has many such electrons, and if they are aligned they create a measurable macroscopic field.

These permanent dipoles (often called simply "spins" even though they also generally include orbital angular momentum) tend to align in parallel to an external magnetic field, an effect called paramagnetism. (A related but much smaller effect is diamagnetism, due to the orbital motion *induced* by an external field, resulting in a dipole moment *opposite* to the applied field.) Ferromagnetism involves an additional phenomenon, however: the dipoles tend to *align spontaneously*, without any applied field. This is a purely quantum-mechanical effect.

According to classical electromagnetism, two nearby magnetic dipoles will tend to align in *opposite* directions (which would create an antiferromagnetic material). In a ferromagnet, however, they tend to align in the *same* direction because of the Pauli principle: two electrons with the same spin state cannot lie at the same position, and thus feel an effective additional repulsion that lowers their electrostatic energy. This difference in energy is called the exchange energy and induces nearby electrons to align.

At long distances (after many thousands of ions), the exchange energy advantage is overtaken by the classical tendency of dipoles to anti-align. This is why, in an equilibriated (non-magnetized) ferromagnetic material, the dipoles in the whole material are not aligned. Rather, they organize into **magnetic domains** (also known as *Weiss domains*) that are aligned (magnetized) at short range, but at long range adjacent domains are anti-aligned. The transition between two domains, where the magnetization flips, is called a Domain wall (e.g., a Bloch/Néel wall, depending upon whether the magnetization rotates parallel/perpendicular to the domain interface) and is a gradual transition on the atomic scale (covering a distance of about 300 ions for iron).

Thus, an ordinary piece of iron generally has little or no net magnetic moment. However, if it is placed in a strong enough external magnetic field, the domains will re-orient in parallel with that field, and will remain re-oriented when the field is turned off, thus creating a "permanent" magnet. This magnetization as a function of the external field is described by a hysteresis curve. Although this state of aligned domains is not a minimal-energy configuration, it is extremely stable and has been observed to persist for millions of years in seafloor magnetite aligned by the Earth's magnetic field (whose poles can thereby be seen to flip at long intervals). The net magnetization can be destroyed by heating and then cooling (*annealing*) the material without an external field, however.

As the temperature increases, thermal oscillation, or entropy, competes with the ferromagnetic tendency for dipoles to align. When the temperature rises beyond a certain point, called the **Curie temperature**, there is a second-order phase transition and the system can no longer maintain a spontaneous magnetization, although it still responds paramagnetically to an external field. Below that temperature, there is a spontaneous symmetry breaking and random domains form (in the absence of an external field). The Curie temperature itself is a critical point, where the magnetic susceptibility is theoretically infinite and, although there is no net magnetization, domain-like spin correlations fluctuate at all lengthscales.

The study of ferromagnetic phase transitions, especially via the simplified Ising spin model, had an important impact on

the development of statistical physics. There, it was first clearly shown that mean field theory approaches failed to predict the correct behavior at the critical point (which was found to fall under a *universality class* that includes many other systems, such as liquid-gas transitions), and had to be replaced by renormalization group theory.

Unusual ferromagnetism

In 2004, it was reported that a certain allotrope of carbon, Carbon nanofoam, exhibited ferromagnetism. The effect dissipates after a few hours at room temperature, but lasts longer at low temperatures. The material is also a semiconductor. It is thought that other similarly-formed materials, such as isoelectronic compounds of boron and nitrogen, may also be ferromagnetic.

The alloy $ZnZr_2$ is also ferromagnetic below 28.5 K.

See also

- Category:magnetic alloys

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Magnetic states
diamagnetism – superdiamagnetism – paramagnetism – superparamagnetism – **ferromagnetism** – antiferromagnetism – ferrimagnetism – metamagnetism – spin glass

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